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Army Ground Vehicle Propulsion

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Army Ground Vehicle Expectations

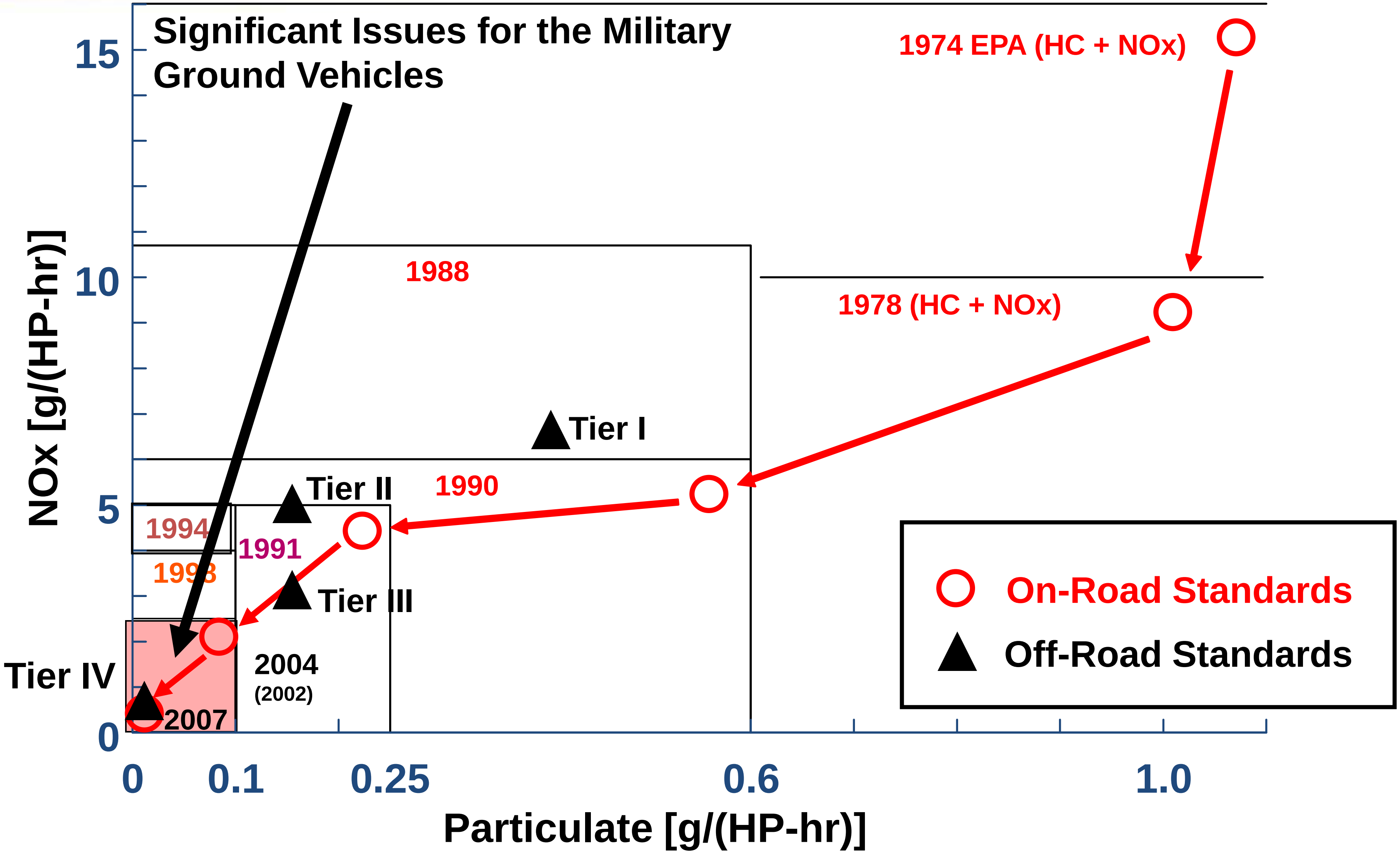
- Demanding ambient conditions ranging from Artic-like to Desert-like
- ‘dirty’ environment – muddy, sandy, and snowy at times
- Must operate on compression ignition fuels – global jet and diesel fuels
- Must have minimal maintenance schedules
- Must protect the occupants
- Need to tow other vehicles, climb steep grades, corner at medium to high speeds, carry around cargo, pull themselves out of ditch while sitting on one track, pivot steer, operate in soft soil
- Increasing need for more on-board electrical power

Army Ground Vehicle Propulsion Challenges

1. Cooling
2. Cooling
3. Fuel Effects
4. Filtration
5. Emission standards

The Army vehicle cooling point is high tractive effort to weight under desert-like operating conditions (ex. 8 ton wheeled vehicle ~0.6 while 30 ton tracked vehicle ~0.7 both at 120 - 125 F ambient)

U.S. Diesel Emission Standards



Engine Emissions Policy

- The Army can not buy 2007 or Tier IV (> 75 bhp) compliant COTS engines and directly integrate into current and new heavy-duty vehicles.

- Combat vehicle: permanent armor/attached weapon system – National Security Exemption (NSE) via **40 CFR, 89.908**

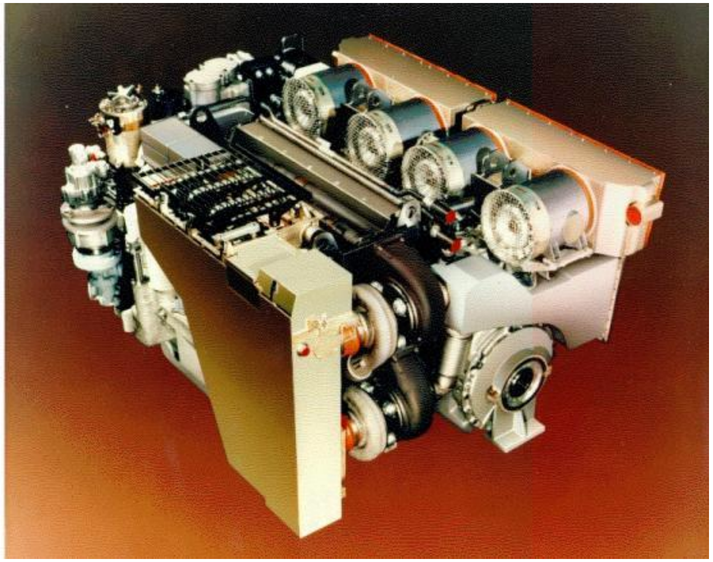
- ‘Tactical Vehicles’
  - ✓ Without ARMOR – NSE from 2004 and 2007 standards (i.e. meet 1998) and Tier IV
  - ✓ With ARMOR – NSE from ALL standards

- Declining availability of COTS engines for Army trucks as suppliers include various engine emissions technologies on engines that negatively impact Army vehicle performance/reliability/durability

High Power Density Propulsion Systems – Combat Vehicles

- Army definition of Propulsion System Power Density (PD):
  - PD = sprocket (wheel) power / total propulsion system volume [bhp/ft^3]
  - Air filtration requirements, thermal management system, transmission, engine, ducting requirements, final drives, fuel tank

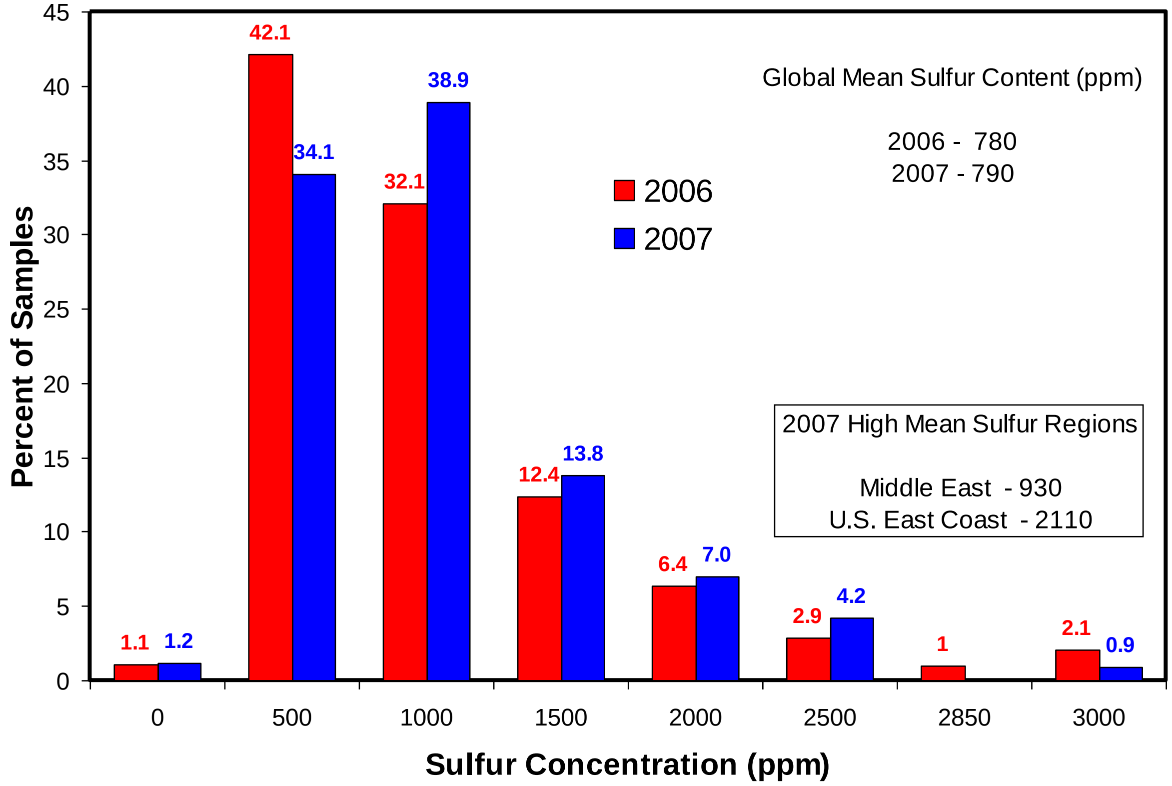
- Bradley FIV or M1: PD = 3
  - example, M1 – gas turbine
    - 291 ft^3 installed volume:
      - Fuel tank 77 ft^3;
      - unused 70 ft^3;
      - transmission 40 ft^3;
      - engine 31 ft^3;
      - air filtration 31 ft^3
  - Bradley FIV: Cummins VTA903 has SHRR of 0.6 BHP/BHP vs. today's COTS > 0.85 BHP/BHP



- Future Combat System PD target ~ 6 (projected to be 4.5)
- Research target: PD > 6-10

JP-8 Property Specification Challenges

- Sulfur content: max. 3000 ppm
  - DF-2 : 15 ppm
- Cetane Index: none
  - DF-2 : > 40
- Density: 0.775 – 0.84
  - DF-2 ~ 0.85
- Lubricity specif. : none
  - DF-2 HFRR < 520



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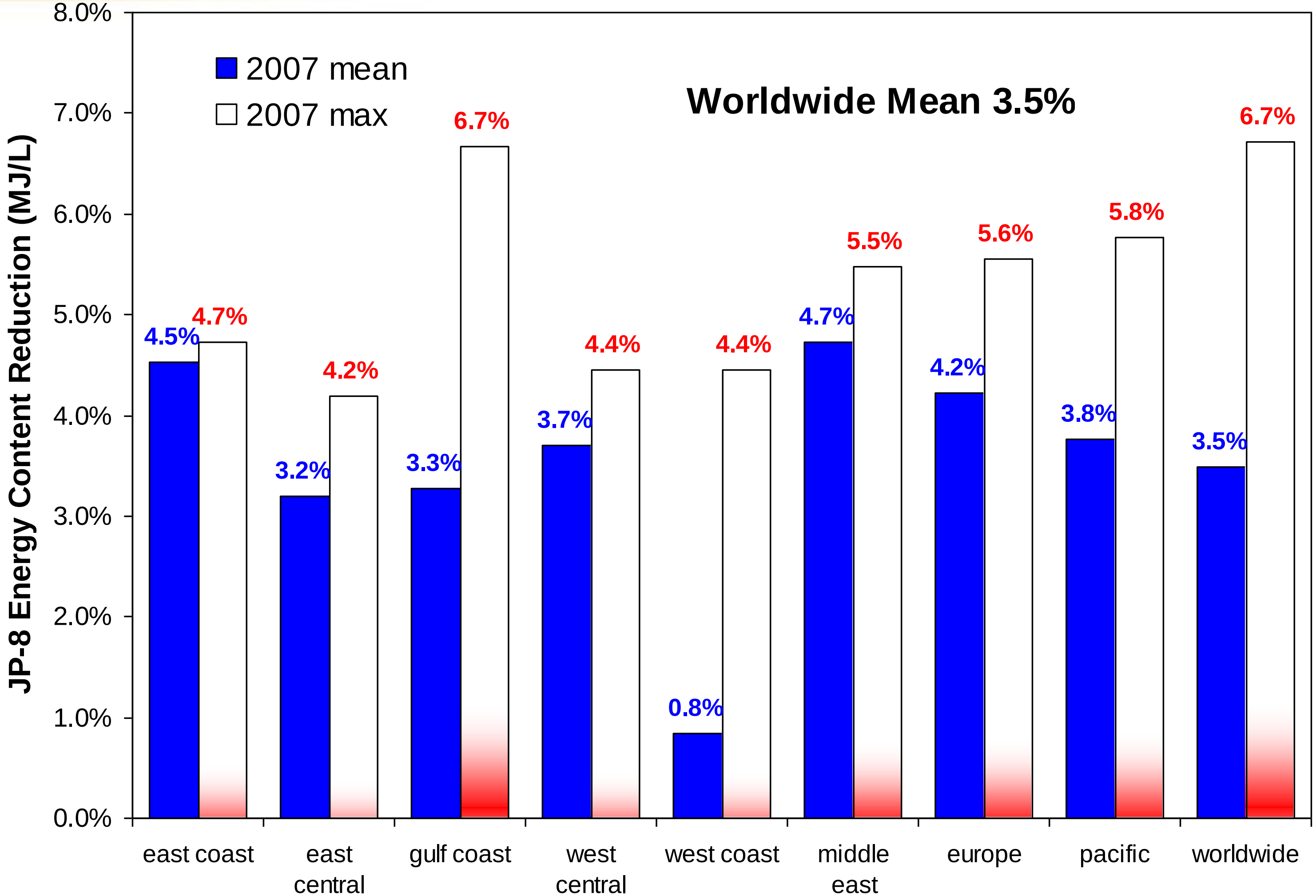
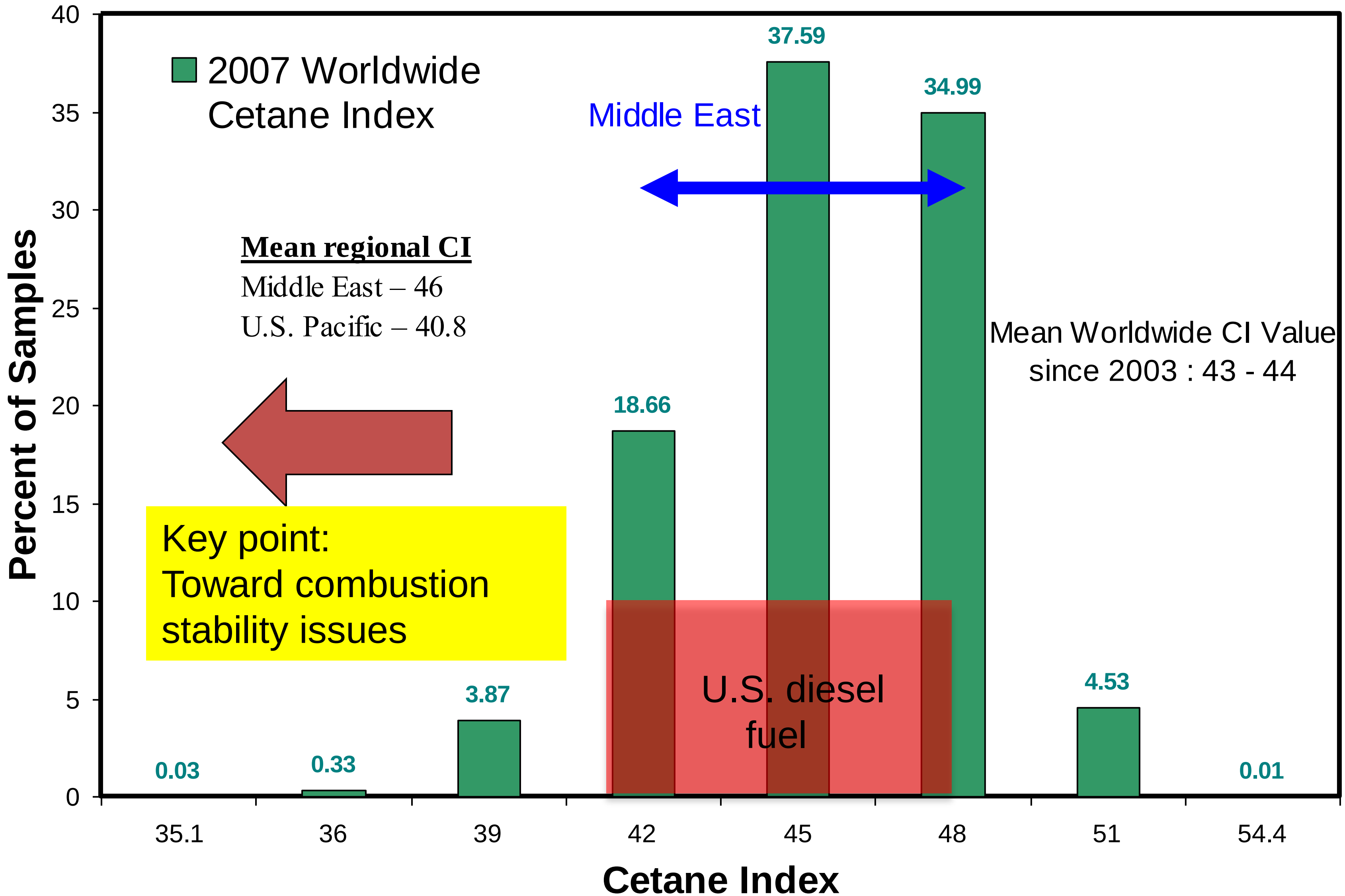
JP-8 Energy Volumetric Energy Content Relative to DF-2



KEY POINT: Lower volumetric energy density implies less energy in the fuel tank and thus reduced vehicle range

JP-8 Cetane Index Worldwide Trend in 2007



PERFORMANCE CHALLENGES: Fuel Economy/Power Density/Electrical Power Trade-offs

- **Vehicle mobility requirements and allotted cooling grill surface area drive final powertrain architecture**

- **Combat vehicles more constrained on grill size**
  - Tend to use specialty engines
  - High tractive effort to weight requirement (cooling issue)

- **Wheeled vehicles may or may not have ram air**
  - Tend to use COTS engines
  - More readily lend for a good combination of power density and fuel economy due to less restrictive mobility requirements and less restrictive cooling air flow (though V-hull design is a challenge)
    - COTS vehicles rely on under vehicle airflow for cooling purposes

- **Generation of electrical power (up to 200 kW)**
  - Reduced power density (additional propulsion system volume)
  - additional cooling system capacity (larger heat exchangers and/or large parasitic fan power)
  - May or may not improve fuel economy as a strong function of duty cycle

CHALLENGE AREAS for Army Ground Vehicles Relevant to ARC

- Hybrid Electric Propulsion
  - High temperature operating capability w/o the need for low temperature air/water cooling system
  - Wide range and highly efficient generators/motors
  - Battery packs with minimal cooling requirements and high volumetric energy density
- 'Standard' propulsion
  - Strategic cooling, advanced cooling concepts, etc.
  - Wide gear ratio transmissions
- Diesel Engines
  - Improved understanding of military relevant fuel combustion phenomena
    - Low and medium temperature chemistry
    - Cold start progression
    - Ignition limits and the impact on engine performance
  - Thermal efficiency augmentation
    - Friction, ancillaries, strategic cooling, etc.
    - Power density considerations
  - Multi-fuel operation and optimization

Current/Recent JP-8 Needs of the Army Addressed by the ARC

- **Evaporation and Spray Penetration Data/Analysis**
  - 0-D model development: TARDEC (evaporation-warm cond.)
  - Optical Engine data – WSU (cold)
  - CFD: University of Michigan (UM) and Laura Decker (WSU)
  - Multi-zone: University of Michigan-Dearborn (pending)

- **Ignition and Generalized Heat Release Analysis**
  - Single Cylinder Measurements: TARDEC & WSU
  - Multi-cylinder measurements: TARDEC & WSU & UM
  - Modeling: TARDEC*, WSU, & UM
    - Laura Decker: zero-dimensional/reduced mechanisms
    - UM: full kinetics with possible reduction

- **Fuel Effects Combustion Compensation**
  - Multi- and single-cylinder: WSU

- **Cold Starting Transient Combustion Behavior**
  - Multi- and single-cylinder: WSU

Army Alternative Fuel Research Needs Addressed by ARC

- **Army Alt Fuels = JP-8 synthetics that are blended or unblended with JP-8 AND ignition limit fuels**

- **Evaporation and Spray Penetration Data/Analysis**
  - 0-D model development: TARDEC (evaporation-warm cond.)
  - CFD: Laura Decker (WSU)

- **Ignition and Generalized Heat Release Analysis**
  - Single Cylinder Measurements: TARDEC & WSU
  - Multi-cylinder measurements: WSU & UM (?)
  - Modeling: TARDEC* & WSU
    - Laura Decker: zero-dimensional/reduced mechanisms

- **Fuel Effects Combustion Compensation**
  - Multi- and single-cylinder: none*

- **Cold Starting Transient Combustion Behavior**
  - Multi- and single-cylinder: WSU

Examples of TA4 Transitions to the Army

- WSU ignition data (JP-8/Sasol JP-8) for internal use
- UM Series HEV tracked vehicle study for internal use
- UM HEV truck concept study for internal use
- WSU closed loop control study for internal use
- CU suspension energy recovery concept study for internal use

KEY INGREDIENTS for TARDEC tech transfer:

- team level interest (TARDEC)
- regular interaction with TARDEC engineer
- support from division level leadership

KEY POINT: ARC TA4 activities are a small percentage of the GVPM overall external and internal R&D and in-house test/evaluation portfolio. Projects must be very relevant to TARDEC team (engineer) for any chance of tech transition.